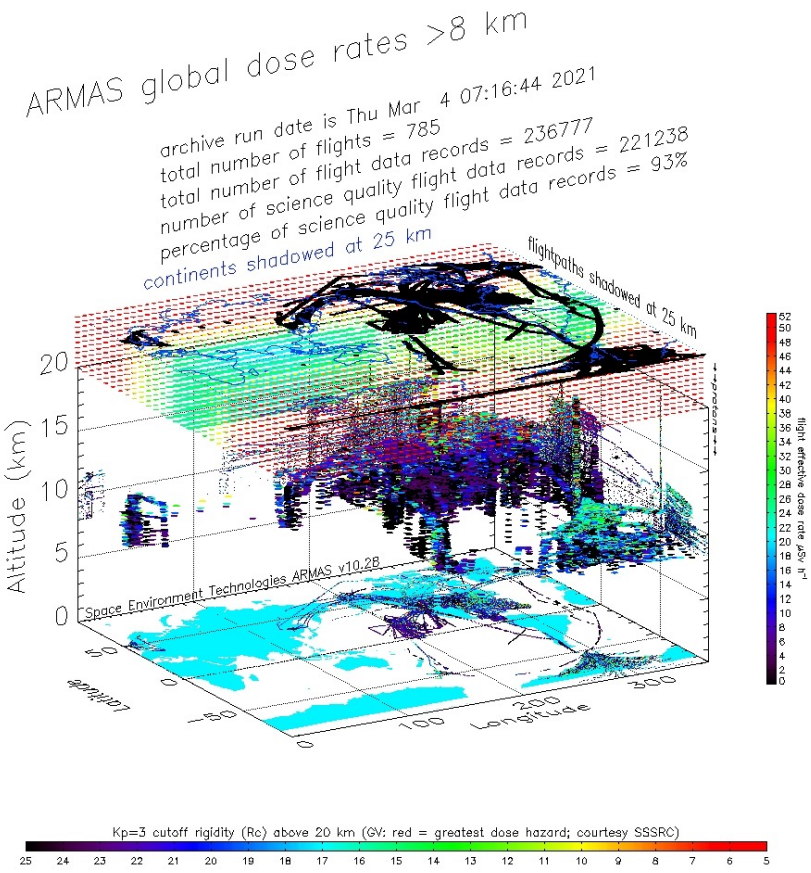
Automated Radiation Measurements for Aerospace Safety - Dual Monitor (ARMAS-DM)

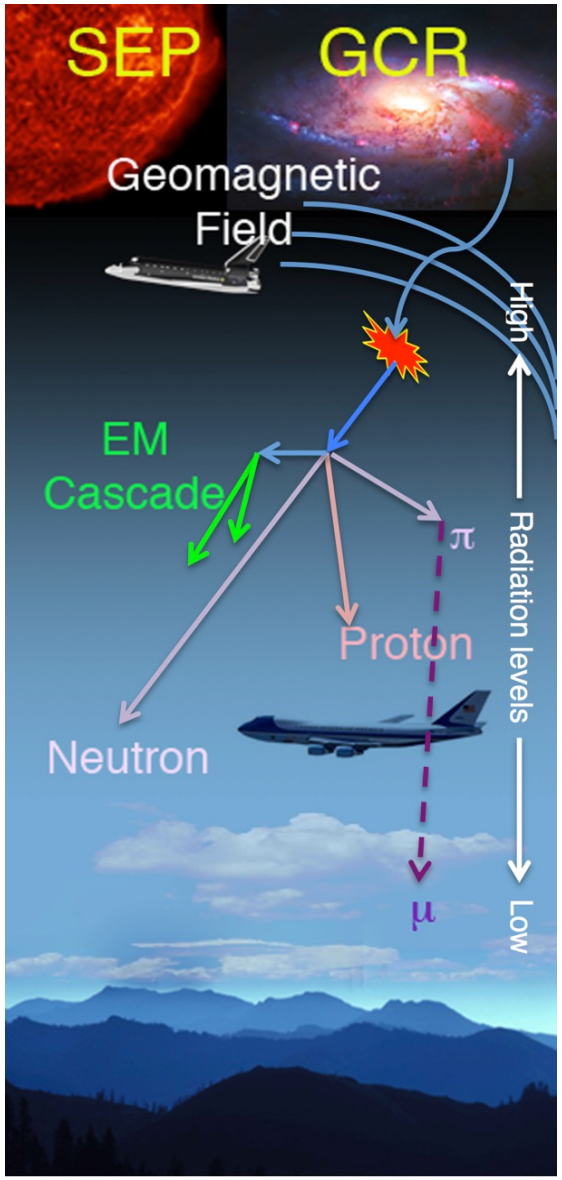
W. Kent Tobiska

Space Environment Technologies

BASELINE RADIATION:
ARMAS global measurements
between 2013-2021

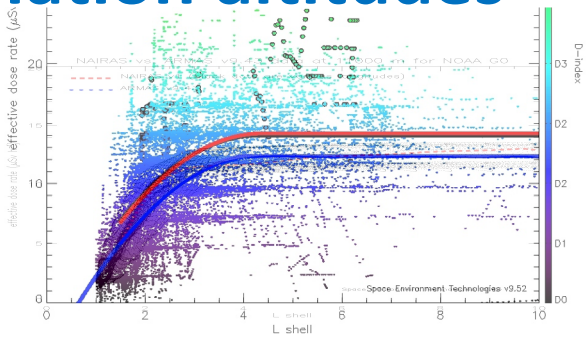


Background: Space weather creates a dynamic radiation environment at aviation altitudes



Modeled GCR dose rate vs. L-shell

Observed dose rate vs. L-shell



Radiation sources above 8 km

- ✓ **<u>Known</u> global phenomenon:** GCRs create a career health issue and source for avionics SEUs
- ✓ **higher latitude phenomenon**
  - ✓ **<u>Known</u> extended major events:** SEPs can affect fleet operations and aircrew/passenger monthly limits
  - ○ **<u>Research area</u> short-term minor events:** secondary radiation from precipitating radiation belt energetic particles are an incremental career health issue

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Where are we today? Progress towards aviation radiation nowcast & forecast

- **DETECTORS**
  - ✓ Geiger counters
  - ✓ Bubble detectors
  - ✓ TEPC
  - ✓ Liulin
  - ✓ RaySure

1950-1990

Step 1: Discovery

- **DETECTORS**
  - ✓ Bubble
  - ✓ TEPC
  - ✓ Liulin
  - ✓ RaySure
  - ✓ ARMAS
- **MODELS**
  - ✓ CARI-6
  - ✓ NAIRAS
  - ✓ PANDOCA

1990-2016

Step 2: Validation

- **DETECTORS**
  - ✓ **ARMAS**
  - ✓ ATED
- **MODELS**
  - ✓ **NAIRAS v1**
  - ✓ **CARI-7**
  - ✓ PANDOCA
  - ✓ KREAM

2017-2020

Step 3: Monitoring

(occasional NAT or NoPAC flights; tech demo regional monitoring; demo data assimilation)

Spring 2021

- **DETECTORS**
  - ✓ **ARMAS**
  - ✓ **ATED**
- **MODELS**
  - ✓ **NAIRAS v2**
  - ✓ **CARI-7**

2021-

Step 4: Nowcast & forecast

(100+ daily flights for track truth, continuous balloon loiter or hi-alt/long endurance regional monitoring; operational data assimilation and demo ensemble modeling)

Global baseline now achieved:

785 ARMAS Flights from 0-107 km in 2013–2021

- ✓ **Agency and Commercial Aircraft flying ARMAS**
  - ✓ **AFRC:** DC-8 (a), ER-2 (d), G-III, SOFIA (B747)
  - ✓ **NOAA**: G-IV (b)
  - ✓ **NSF**: G-V (c)
  - ✓ **FAA**: Bombardier Global 5000
  - ✓ **Commercial**:
    - Boeing 737, 747, 757, and 777
    - Airbus 319 and 320
    - Bombardier Q200
    - CRJ 200, 700; Embraer 175
- ✓ **Balloons**
  - ✓ **World View Enterprises:** Stratollites (f)
  - ✓ NSL: test balloons
- ✓ **NASA space stations**
  - ● ISS (Low Earth Orbit)
  - ○ Gateway (Lunar Orbit)
- ✓ **Proprietary vehicles**
  - ✓ **Perlan** Stratospheric glider (e)
  - ✓ **Virgin Galactic** SS2 and WK2 (g)
  - ✓ **Blue Origin** New Shepard (h)
  - ● Cubesat
  - ○ Lunar lander

✓ Flown
● In progress
○ Potential

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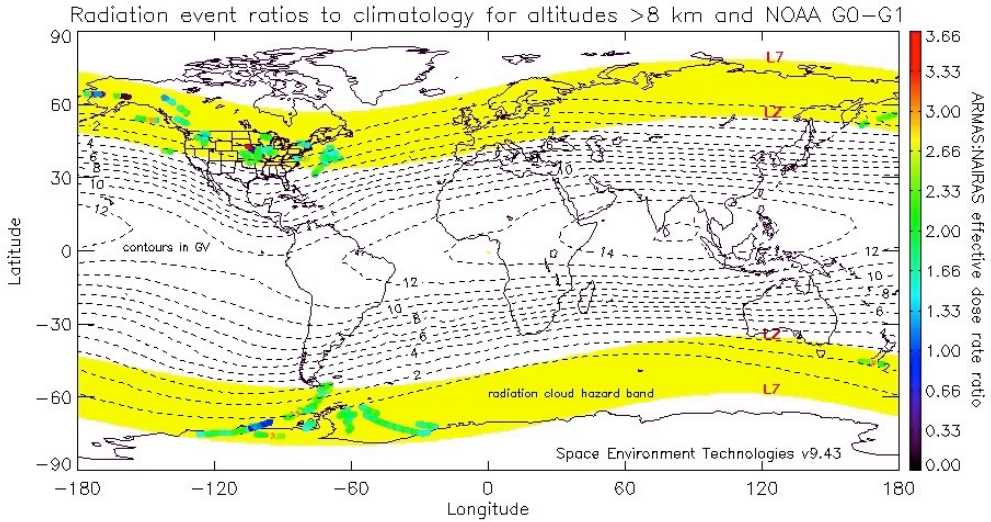
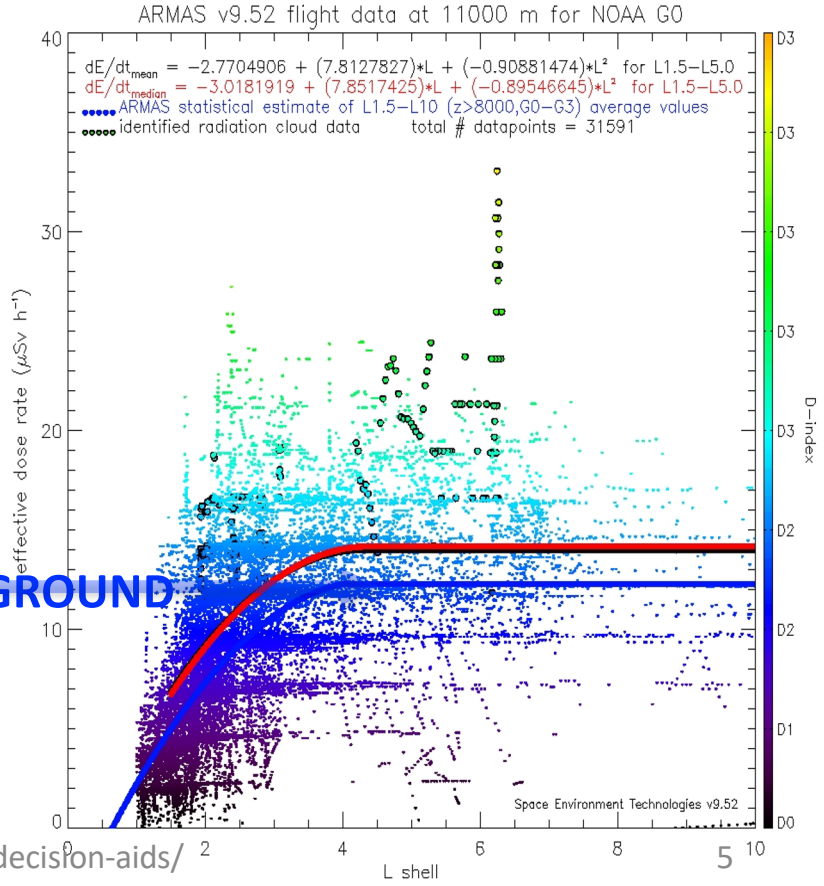
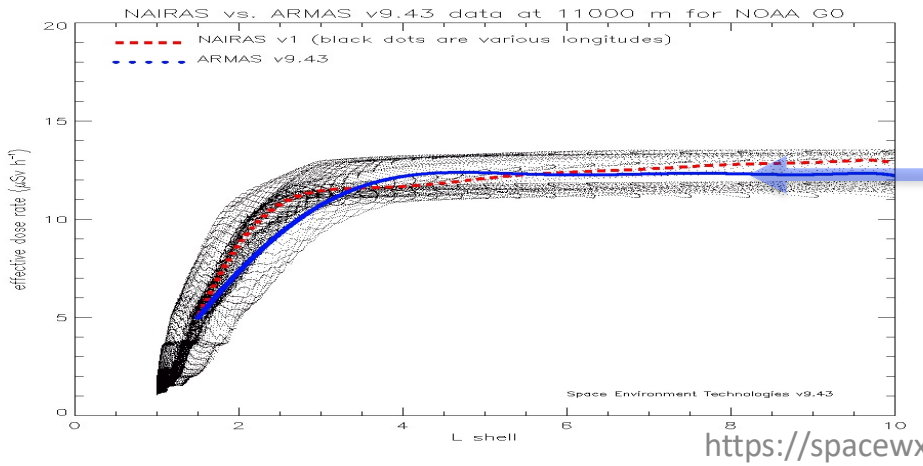
Science question: why do the dose rates at 2<L<7 and ≥11 km during geomagnetic quiet conditions rise above GCR background?

GREEN dots = 2 times background



ARMAS GCR + REP MEASURED DOSE





GCR BACKGROUND

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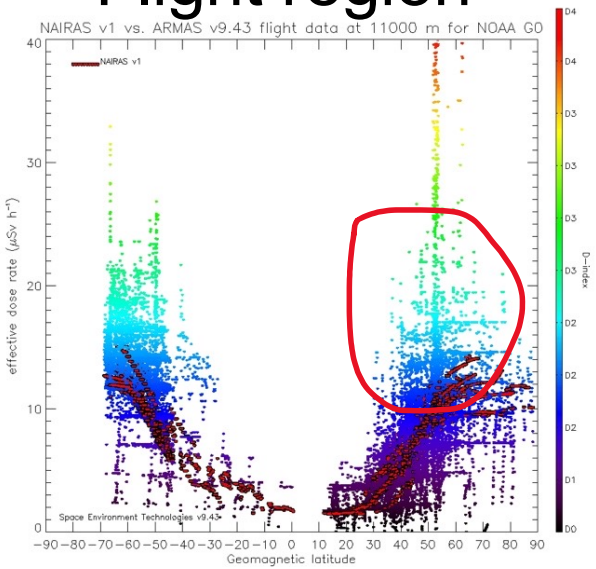
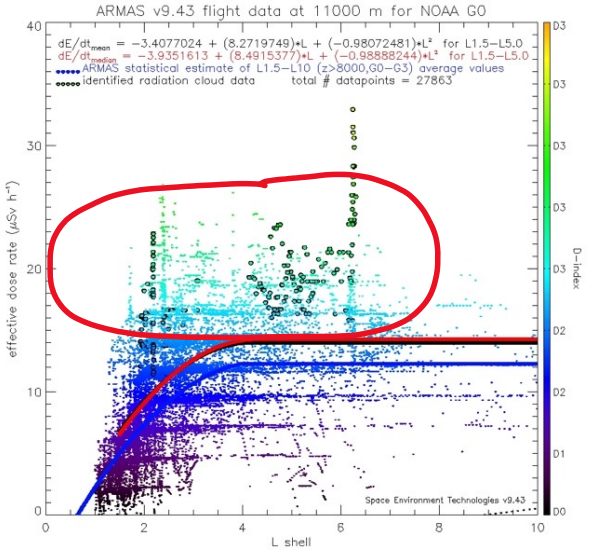
ARMAS Dual Monitor WVE balloon will demonstrate 24/7 operations for 30-days and will address science

Flight region





Instrumentation

Flight demo

ARMAS Dual Monitor will fly through multiple domains in 2021-2022

Flight region	Date	Instrumentation
Troposphere	07/22	ARMAS FM7 in at least one of: ✓ ER-2 ✓ Business jet ✓ Commercial flight
Stratosphere	07/22	ARMAS FM5, ATED, γ-ray spectrometer, Liulin, thermal neutron monitor ✓ WVE Stratollite balloon (30-days) ❍ UAV (concept development)
	2022	ARMAS FM5 & FM7 multiple flights on WVE
Thermosphere	06/21	ARMAS FM8A ✓ TAGSAT2 (sun-syn, 97.5º, 550 km)
	01/22	ARMAS FM9 ✓ ISS (28.5º, 450 km)
	07/22	ARMAS FM8B ✓ SWAP-E (sun-syn, 97.5º, 550 km)

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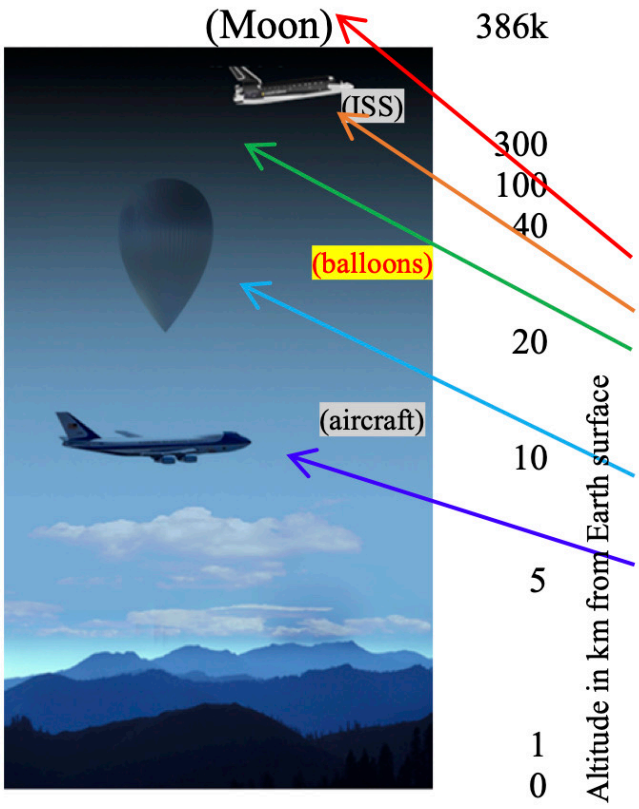
BACKUP SLIDES

ARMAS Program Milestones



Milestones toward achieving operational radiation monitoring

Modeled radiation (NAIRAS) based upon	Measured radiation (ARMAS) observed at
○ **Moon** (LRO Crater)	○ **Moon** (LSITP lander)
✓ **LEO** (ISS, satellites)	• **LEO** (hosted P/Ls, cubesats, ISS)
✓ **Suborbital** (sounding rockets and commercial vehicles to top of atmosphere)	✓ **Suborbital** (Unity Space Ship Two, New Shepard)
✓ **High altitude** (scientific balloons, ER-2)	✓ **High altitude*** (ER-2, World View balloon)
✓ **Aviation altitude** (commercial carriers, agency research aircraft)	✓ **Aviation altitude** (commercial carriers, U.S. Gov't research and operational aircraft)

Legend: ○ Incomplete ✓ Complete ● Proposed/in process ***this project**

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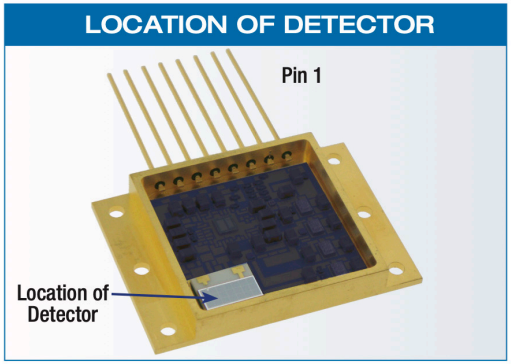
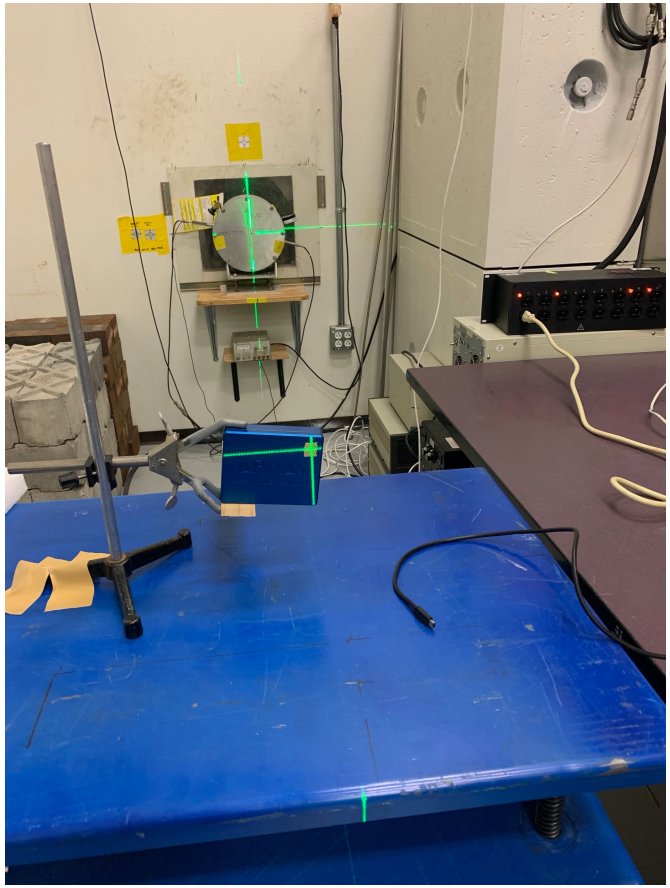
Improving operational data: Calibration of ARMAS dose rate in tissue with the TEPC





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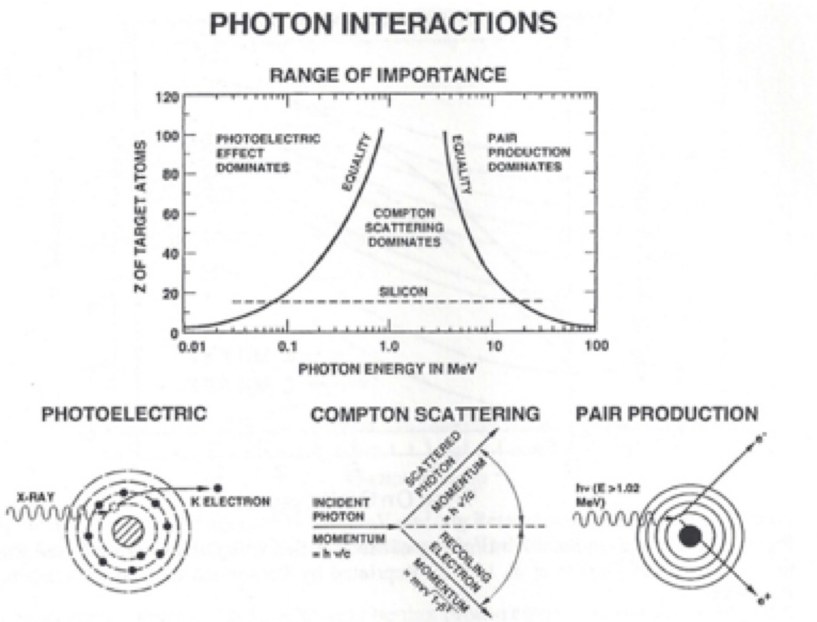
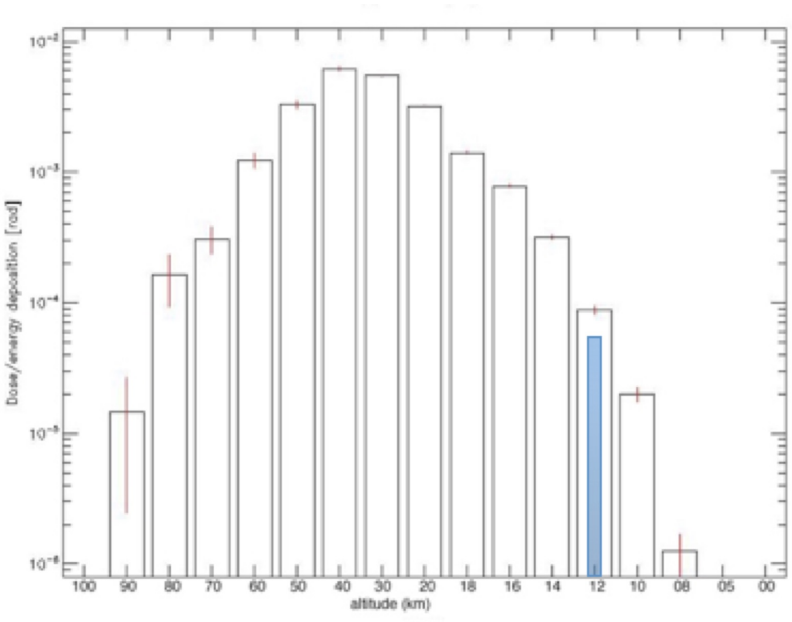
Improving scientific understanding: Source of excess radiation – hypothesis (1)

- **Hypothesis**:
  - γ-rays are at same dose levels as measured by ARMAS detector via Compton scattering in silicon





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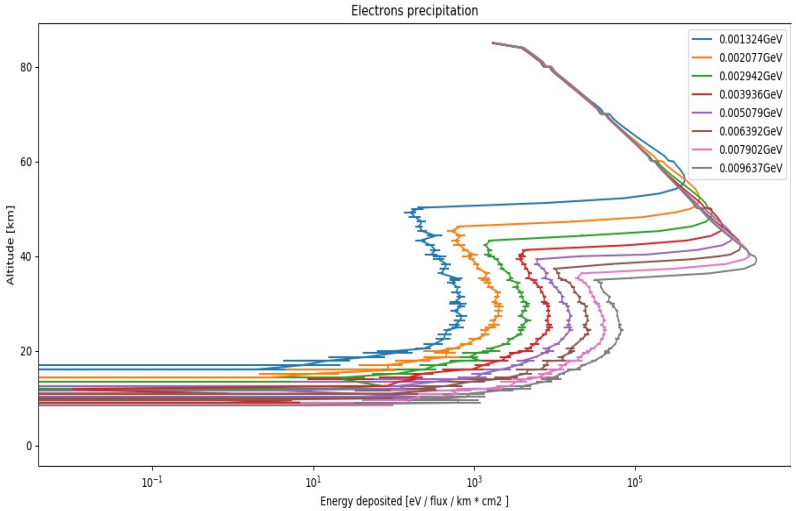
Improving scientific understanding: Source of excess radiation – hypothesis (2)

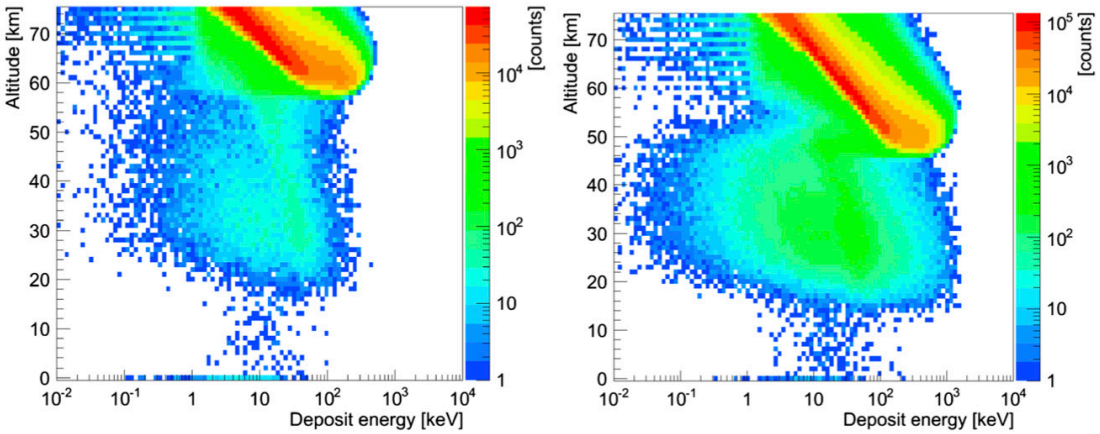
- **Hypothesis**:
  - Electrons precipitation into mesosphere and create resultant Bremsstrahlung γ-rays



Credit: G. Gronoff

0.6 Mev

20.0 MeV



Credit: Tsurutani et al., 2016

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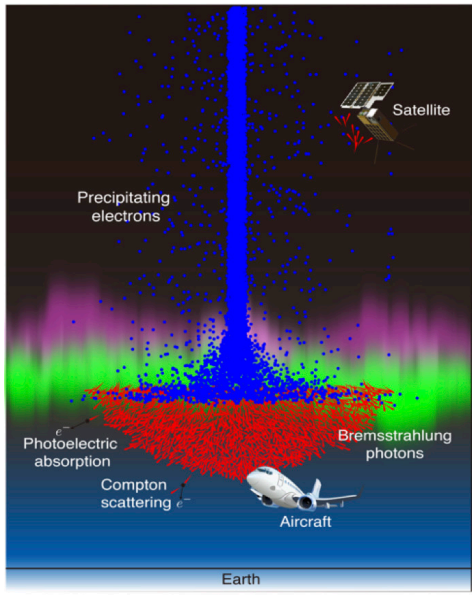
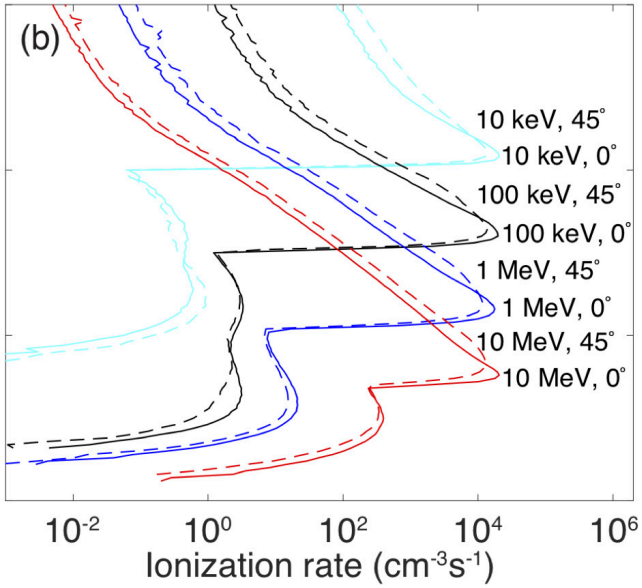
Improving scientific understanding: Source of excess radiation – hypothesis (3)

- **Hypothesis**:
  - Electrons precipitation into mesosphere and create resultant Bremsstrahlung γ-rays



Credit: Marshall



Credit: Marshall

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Improving state-of-the-art radiation monitoring: ARMAS Flight Module 7 (FM7) has Bluetooth paired with iOS devices using the ARMAS app

Features:

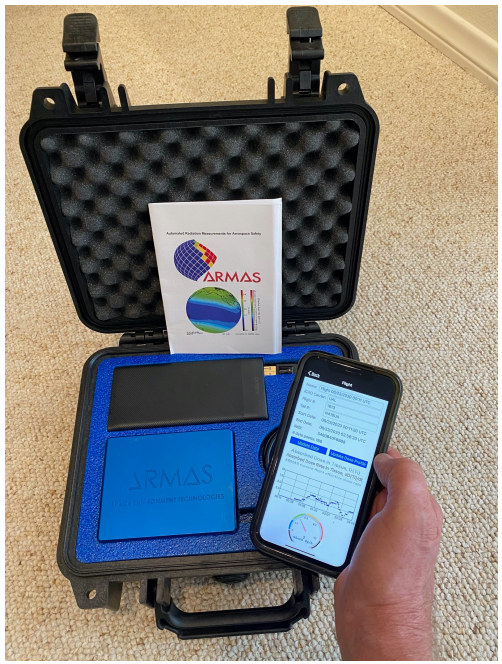
- ✓ Measures absorbed dose in silicon
- ✓ Small size, mass, and power
- ✓ Data retrieval using Bluetooth to pair with iOS ARMAS app available from Apple Store
  - Current and post-flight dose rate status displayed on app that is paired with FM7
  - Dose rate can be transmitted to ground using WiFi
- ✓ Real-time dose rates: measured absorbed (Si) and derived absorbed (Ti), dose equivalent, ambient dose equivalent, and effective

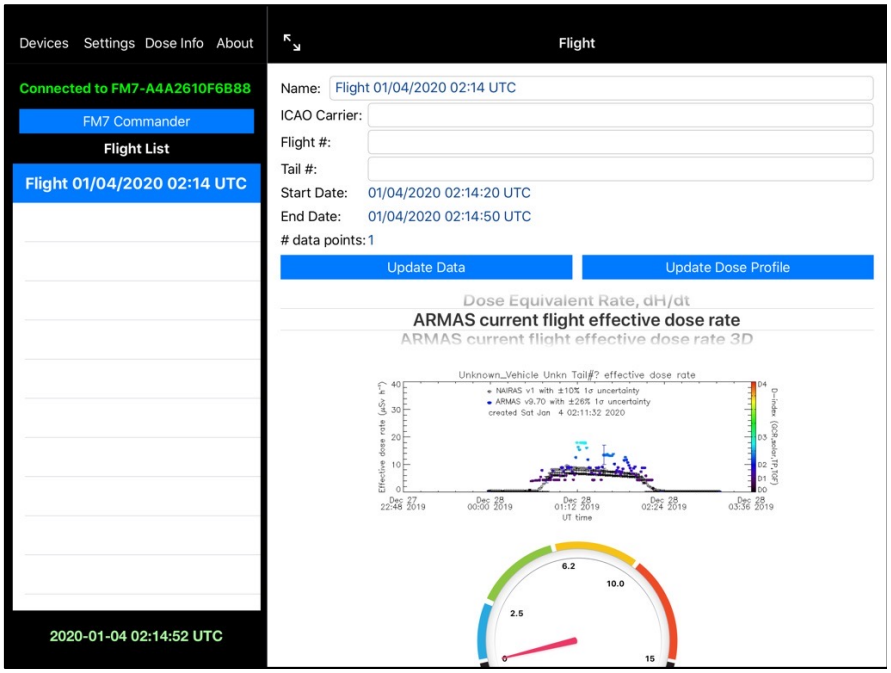
Availability:

- ✓ 15 units produced 2018-2021
- ✓ 4th production run Aug 2020

ARMAS iOS app:

- ✓ Available in the Apple Store for general public, space weather afficionados, frequent flyers, professional crew members





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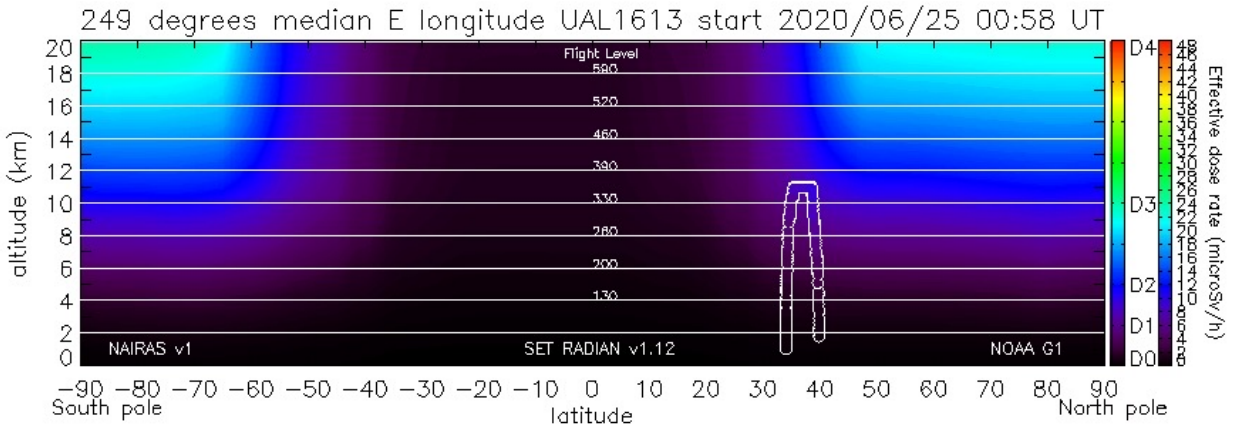
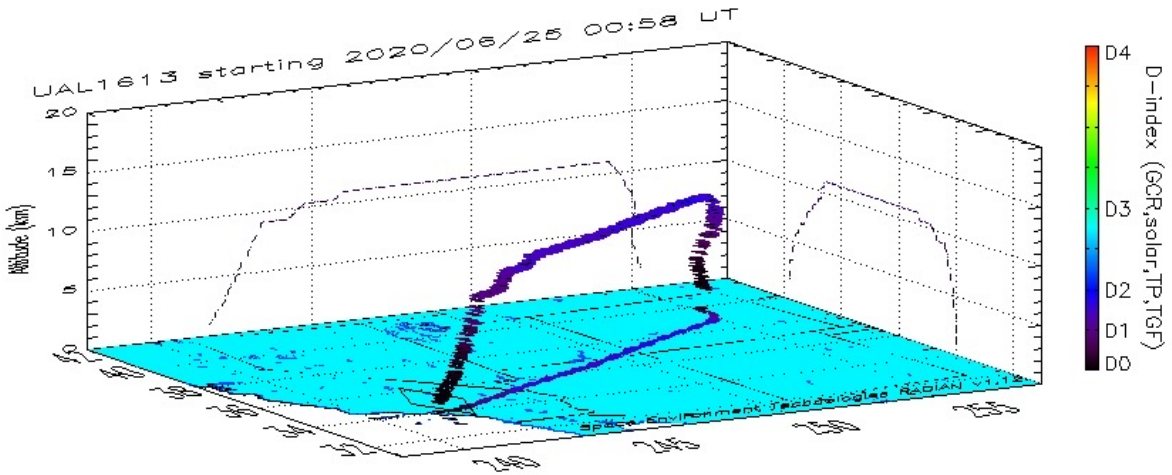
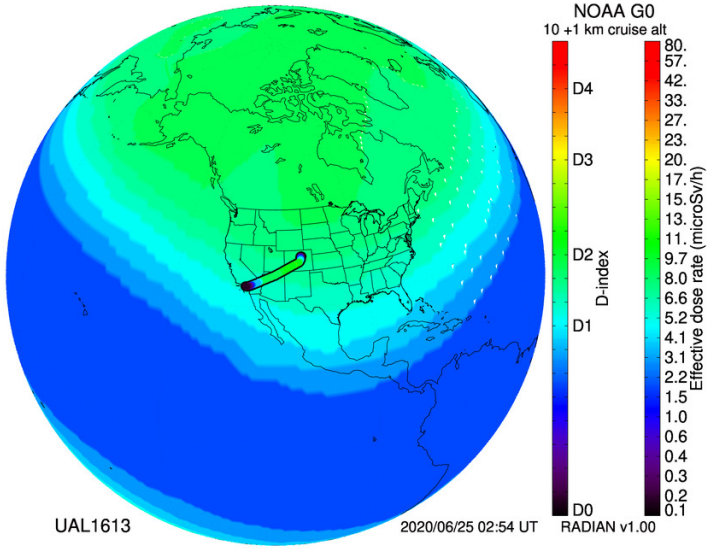
Providing global data: ARMAS measurements integrated with NAIRAS v2 form the RADIAN data cube





RADIAN now provides flight tracks for any aircraft in the world (via ARMAS iOS app)



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